SUGGESTED APPROACH TO GEOLOGIC HAZARDS ORDINANCES IN UTAH

by
Gary E. Christenson

UTAH GEOLOGICAL AND MINERAL SURVEY
a division of
UTAH DEPARTMENT OF NATURAL RESOURCES
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UTAH GEOLOGICAL AND MINERAL SURVEY

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INTRODUCTION

The purpose of geologic hazards ordinances is to encourage prudent land uses in areas of geologic hazards for the protection of the health, safety, and property of the citizens of the city or county enacting the ordinance. Geologic hazards can be considered at various times during planning and development, but in general are best considered early in the process. Some geologic hazards cannot be mitigated or are too costly to mitigate and, therefore, are best avoided. Other hazards are easily mitigated and need not influence land use significantly as long as the hazard is identified. Because of this, general hazards information should be utilized in developing local master plans and zoning ordinances so that land use can then take into account geologic hazards. Identification of hillside protection zones, critical environmental zones, and sensitive land zones are common ways of addressing hazards in zoning ordinances. Development in such zones is either prohibited or restricted unless certain requirements are met prior to development.

In cases where master plans and zoning ordinances have already been adopted, amendments can be used to address hazards, although it is often too late to change the existing land use to one that is more compatible with the hazards. Geologic hazard or sensitive land overlay zones are effective for use in areas where zoning ordinances have already been implemented. The overlay zone (or zones, if each hazard is considered separately) includes those areas in which hazards have been identified and places certain restrictions on development. This overlay zone(s) can be placed over the existing zone maps requiring that development also conform to the overlay zone regulations.

Geologic hazards can also be addressed later during site development in development codes and subdivision ordinances. In these documents, identification and mitigation of hazards are generally required prior to issuance of building permits in areas considered subject to hazards. From the standpoint of addressing geologic hazards, development codes are more comprehensive because all development and not just residential subdivisions must comply. One drawback of development codes and subdivision ordinances is that geologic hazards will only be addressed in areas where they have been identified by local government, and many local governments lack the expertise to identify hazard areas. Maps delineating geologic hazards prepared by qualified geologists can be used to effectively implement these ordinances. These types of codes and ordinances may officially reference and use such maps without specifically defining zones, in contrast to zoning ordinances which could use the maps to define the geologic hazards overlay zone(s).

PURPOSE AND SCOPE

The purpose of this report is to outline a series of steps which can be followed by local government in order to effectively consider geologic hazards. These steps may be incorporated into: 1) zoning ordinances in hillside protection zones, critical environmental zones, or geologic hazards overlay zones; or 2) site development codes and subdivision ordinances. The report is written for local government planners and sets forth an approach which should ensure consideration and mitigation of hazards and at the same time maintain maximum flexibility in implementation and land-use decision making. This report is not a comprehensive review of all possible approaches or types of ordinances in which geologic hazards may be addressed. It is also not a model ordinance, although it includes some definitions which may be used in an ordinance. A glossary of terms is included at the end of the report.

The scope of work for this report included telephone discussions with various city and county planners and other local government officials throughout the state to determine how, and in what documents, geologic hazards are presently addressed. Copies of the documents, generally zoning or subdivision ordinances, were then collected and reviewed. No attempt was made to collect all city and county master plans and ordinances, so it is possible that a pertinent document was not reviewed if it was not identified in phone conversations. Hazards ordinances from selected cities and counties in other states and literature regarding the variety of approaches to pre-development hazards reduction were also reviewed.

SUMMARY OF SUGGESTED APPROACH

The approach presented in this report is one that is already in practice to varying degrees in Utah and other states. It has proven effective in California and is being advocated and to some extent implemented by Wasatch Front cities and counties through the efforts of Wasatch Front county planners and geologists and the Utah Geological and Mineral Survey.

The first step in addressing geologic hazards in an ordinance is to identify hazard areas. In zoning ordinances and master plans, this is done through area-wide mapping prior to adoption. In development codes and subdivision ordinances this is commonly done on a case-by-case basis by the planning commission. The latter is not fool-proof because planning commissions and staff may lack the necessary expertise, and for effective implementation a qualified geologist should be utilized to review all development and identify which may be in hazard areas.

Once the possible existence of a hazard(s) is determined, the ordinance should include a means of requiring geotechnical investigations performed by qualified engineering geologists and engineers to address hazards and recommend appropriate action prior to development. These investigations may find that no hazards exist at the site and recommend that no action is necessary. If the hazard is found to exist and development is still proposed, recommended actions may include site abandonment, land-use restrictions such as setbacks from faults, mandatory disclosure of hazards to potential buyers, reduced density, placement of engineered structures, and/or recommendations for further studies.

In the final step, reports of these investigations along with recommendations for action to mitigate hazards should be submitted to the governmental entity and reviewed by qualified engineering geologists and engineers. If reviewers believe the investigations are sufficient and mitigating measures satisfactory, they should recommend approval of the development. If the investigation does not adequately or accurately address hazards or if recommended mitigation measures are thought to be inadequate, the reviewers should not approve the plans and recommend that either discussions be initiated to solve problems or that further study be performed. If the report shows the hazards cannot be adequately mitigated for the proposed land use, reviewers should recommend disapproval.

GEOLOGIC HAZARDS IN UTAH

Many of the geologic processes which have shaped Utah's varied and rugged topography over the last few million years remain active today. Uplift of the Wasatch and other mountain ranges in central and western Utah is episodic and accompanied by large earthquakes. The resulting steep mountainsides and high elevations are prone to rapid erosion and slope instability, and are a source of flood waters. These are all natural geologic events and processes, but they are commonly termed geologic hazards because they adversely affect man and his works. In 1983, 22 of Utah's 29 counties were covered by federal disaster declarations because of geologic hazards, primarily flooding, debris flows, and landslides (Anderson and others, 1984). Although not as extensive, substantial damage was also incurred in 1984. The cost of property damages and number of lives lost during 1983 and 1984 are relatively small compared to those expected during a major earthquake along the Wasatch Front. Such losses can be greatly reduced by ordinances regulating land use, but to do so requires an understanding of the nature and extent of the hazards.

SLOPE FAILURES

The slope failure hazard in Utah was dramatically demonstrated in 1983 when the Thistle landslide blocked Spanish Fork Canyon and severed highway and rail connections between the Wasatch Front and areas to the east. This landslide was the most costly in U.S. history and has had lasting adverse economic impacts in Utah. Thistle was an old landslide with documented previous movement and was one of several old landslides, chiefly slumps and earth flows, that were reactivated by an extended period of abnormally high precipitation that began in September 1982. These types of movements represent but one aspect of the slope failure hazard. Debris flows and mud flows are another type of failure common in Utah. They may be generated by cloudburst floods, but in 1983-84 many occurred during rapid spring snowmelt as steep slopes with thick accumulations of colluvium and debris became saturated and failed. If a failed mass reaches a steep drainage, particularly one with a stream flowing in its channel, it may be mobilized into a slurry of mud and rocks that travels down the drainage and is eventually deposited in the channel or at the canyon mouth. Other types of slope failure found in Utah include rock slides and rock falls common to areas of steep, barren rock outcrop.

Slope failures are most common where slide-prone geologic materials are found at high elevations in areas of steep slopes. These conditions exist chiefly in the Wasatch Range, the Uinta Mountains, the high plateaus and steep canyons of central and southern Utah (figure 1). Ancient landslide complexes with varying degress of modern activity occur throughout these areas. In 1983 and 1984, major slope failures (debris flows, slumps, earth flows) and resultant damage occurred in the Wasatch Range and in the plateau areas of Sevier and Sanpete Counties. Slopes in the more arid parts of the Colorado Plateau of eastern Utah are generally stable under present conditions. Slope failures in the mountains of the Basin and Range of western Utah are also less common due to their aridity and the predominance of competent rock types. However, rock falls and debris flows occur in both the Colorado Plateau and Basin and Range provinces.

Slope failure hazards can generally be identified, mapped, and mitigated. Although few hazard maps are presently available, slopes susceptible to failure can be shown at generalized

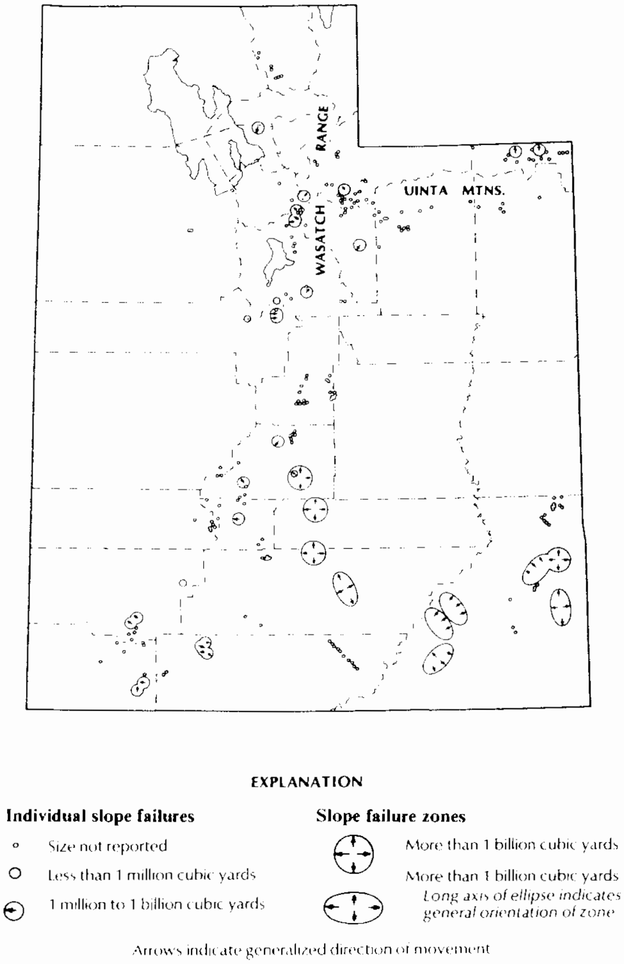

Figure 1. Major slope failures in Utah (adapted from Shroder, 1971). Map shows chiefly slump/earth flow failures and has not been updated to reflect movements after 1971.

scales through geologic mapping of previous failures, failure-prone geologic units, and slope steepness. Site-specific investigations can be performed to evaluate the stability of particular slopes. Various engineering techniques are also avialable to stabilize slopes, and slope failure hazards can also be mitigated through land-use and land-development regulations.

EARTHQUAKES

Earthquakes have the potential for inflicting a greater loss of life and property in a single event than all other hazards in Utah. Earthquakes may have varied and wide-ranging effects, depending on their location, size, and the geologic conditions in the affected area. Small-magnitude earthquakes are common in parts of Utah but are rarely felt and cause little damage. Although no large earthquakes have occurred in densely populated areas of Utah in historical times, evidence indicates that large earthquakes have repeatedly occurred along the Wasatch Front. Although the Wasatch Front has not experienced the effects of a large-magnitude earthquake, such earthquakes have occurred in neighboring states (1959 Hebgen Lake, Montana; 1983 Borah Peak, Idaho) which demonstrated the type of effects that can be expected in Utah. Hazards accompanying earthquakes include ground shaking, surface fault rupture, soil liquefaction, tectonic subsidence, and seismically induced slope failure and flooding. Severe ground shaking represents the greatest hazard during an earthquake because it affects large areas and induces many of the secondary effects associated with earthquakes. Flooding resulting from earthquakes may be caused by increased spring discharge, disruption of surface drainage, dam failure, tectonic subsidence near lakes or in shallow ground-water areas, and/or seiches generated in standing bodies of water.

In general, the area of greatest earthquake hazard in Utah extends in a north-south zone through the center of the state (figure 2) and is a part of what is termed the Intermountain seismic belt from Montana to southwestern Utah. This zone is characterized by numerous active and potentially active faults, and by relativley high levels of historic seismicity. The hazard is considered greatest in northern Utah along the Wasatch, East Cache, and Hansel Valley fault zones. However, significant hazard is present in southern Utah along the Hurricane, Washington, and Sevier-Elsinore fault zones (figure 2). Faults are found in western Utah, but geologically these appear less active and they lack associated earthquakes. The earthquake hazard in the Colorado Plateau of eastern Utah is also low relative to the Intermountain seismic belt.

Many of the earthquake hazards listed above affect large areas and are difficult to identify and map. The extent and severity of ground shaking depends on the location and size of the earthquake and geologic site conditions. Ground shaking cannot be avoided; the hazard can only be mitigated through earthquake-resistant design and construction. Areas of high liquefaction potential may also be unavoidable, but liquefaction hazards can be mitigated using various site preparation techniques and foundation designs. Both liquefaction and ground-shaking hazards affect different types of buildings in different ways, and mitigation techniques will vary depending on type and use of buildings. Other earthquake hazards such as surface fault rupture and seismically-induced slope failure are much more restricted in areal extent and occur in more easily defined areas. Surface fault rupture hazards usually must be mitigated through avoidance because structures cannot be designed to withstand displacements in foundations. Mapping seismic slope failure hazards requires more information than general slope failure hazards, but mitigation techniques are similar. Seismically induced flood hazards generally cannot be accurately mapped and even preliminary estimates require detailed studies.

ADVERSE SOIL FOUNDATION CONDITIONS

Several types of naturally occurring materials are deleterious to foundations and pose a threat to permanent structures. These materials include expansive, collapsible, and gypsiferous soils. Expansive soils are those containing a high percentage of clays which expand and contract when wetted

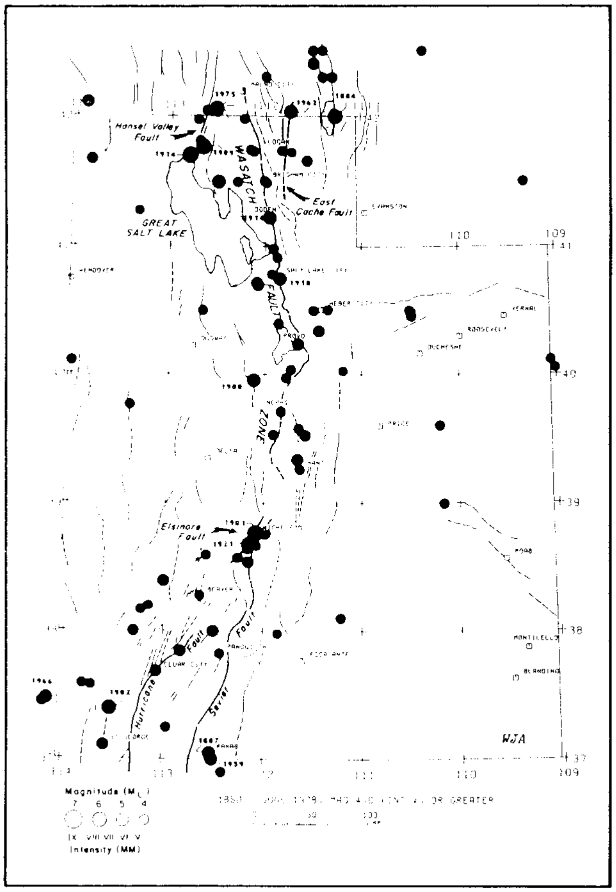

Figure 2. Historic earthquakes of magnitude four or greater and possibly active faults in Utah (Arabasz and others, 1979).

and dried. Forces generated during expansion and ground subsidence accompanying shrinking are sufficient to crack walls and foundations of some structures. Subsidence causing structural damage may also occur in soils subject to hydrocompaction. These soils are termed collapsible because they undergo a volume decrease when wet. Collapsible soils occur in geologically young materials (debris- and mud-flow deposits, wind-blown silt) characterized by a loose "honeycomb" structure resulting from deposition in a moisture-deficient environment. Once wetted, this soil structure collapses and the ground surface settles, causing damage to overlying structures. Subsidence may also accompany dissolution of gypsum or other soluble materials if present in foundation soils.

Expansive soils are found in many parts of Utah and generally result from the weathering of shale and volcanic rock, chiefly tuff. They are locally present along the Wasatch Front, particularly in Utah County, but are more widespread in the Colorado Plateau of central and southern Utah. Collapsible and gypsiferous soils are common in southwestern Utah, particularly along the base of the Hurricane Cliffs (Cedar City, Hurricane), and have been found to the north in the Scipio, Nephi, and Richfield areas.

Problem soils occur throughout Utah and generally cannot be avoided during develoment. Information on the distribution and severity of problem soils is lacking, but they can be recognized by trained geologists and engineers, and most soil problems can be mitigated through proper foundation engineering.

FLOODING

Stream flooding from storms and runoff is probably the most widely distributed and frequently occurring of Utah's geologic hazards. Spring snowmelt is responsible for most flooding along Utah's streams and is to some extent predictable. Cloudburst floods account for more localized but often very destructive flooding and can occur with little warning. Another type of flooding which has caused considerable damage in Utah is the rise of lake levels, particularly of Great Salt Lake and Utah Lake. Flooding may also result from a rise in the shallow water table in response to high stream and lake levels, heavy precipitation, and excess irrigation. Flooding of topographically low areas and subsurface structures such as basements and septic tank soil absorption fields is the major impact of rising water tables.

Although flooding has been reported along nearly all of Utah's major streams, it most commonly occurs in streams draining the Wasatch Range, Bear River Range, Uinta Mountains, and the high plateaus of central and southern Utah. Flooding due to rises in lake levels is generally confined to the closed basins of western Utah, although recent high levels in reservoirs and lakes such as Bear Lake have caused damage. Damage has been greatest along the Wasatch Front where there is extensive development along the Great Salt Lake and Utah Lake. Shallow ground water is also found in many of the basins of western Utah, but the highest water tables and greatest reported flooding have occurred along the Wasatch Front, the valleys of the Wasatch Range and Uinta Basin, and the Sanpete and Sevier Valleys of central Utah.

Flooding is a hazard which can be identified, mapped, and mitigated. Federal programs adopted by most local governments address most stream flooding (although concern exists as to the adequacy of the programs), but lake and gound-water flooding are generally not addressed. With study, these hazards can also be defined as is presently underway for the Great Salt Lake and Utah Lake. However, information on lake and ground-water levels in most areas is lacking and much additional work is required to adequately define these hazard zones.

OTHER HAZARDS

Many other geologic hazards, generally less widespead, are found in Utah. Subsidence and ground cracking, probably due to ground-water withdrawal, have occurred in the Milford area, and similar subsidence may potentially occur in other areas where underground fluids (including oil and gas) are "mined." Collapse of underground caverns and mines and the failure of plugs in vertical shafts have caused local surface subsidence. Subsidence due to compression and decomposition of organic materials in bog or swamp areas and the natural production of methane from such deposits (as along the east shore of Great Salt Lake) may pose hazards to structures. Snow avalanches also present hazards to structures and corridors (highway, pipelines) as well as to skiers and ski areas. Soil erosion and stream downcutting threaten to reduce the productivity of Utah's agricultural and range land by removing top soil and lowering water tables. Sediment carried in streams from these areas fills reservoirs and debris basins, reduces their capacity, and increases maintenance costs. Shifting wind-blown sands in the more arid parts of the state may also present hazards. Although no active volcanos are found in Utah, lava flows less than 1000 years old are found near Milford, and periodic episodes of basaltic volcanism have occurred during the Quaternary period in an area from Delta to St. George. A more significant volcanic hazard is presented by airborn ash from explosive volcanic activity in neighboring states to the west.

AVAILABILITY OF EXISTING GEOLOGIC HAZARDS INFORMATION

The approach to geologic hazards in local government ordinances will depend to some extent on the availability of hazards information. Where available, detailed hazards maps are of great value in delineating areas where hazards must be considered in ordinances. If such maps are not available, other sources of information (published literature, geologic maps, consulting reports) may be used to assess the location and severity of hazards and perhaps to produce maps at usable scales. In Utah, the availability of maps and information varies from essentially none to detailed hazards maps specifically prepared for use in an ordinance. The cities of Provo and Salt Lake have contracted with private consultants to prepare geologic hazards maps at scales of 1:1,200 and 1:24,000, respectively. The UGMS has prepared general multihazard maps for Perry (Lund, 1981), Ballard (Christenson, 1981), the St. George area (Christenson and Deen, 1983), Smithfield (Christenson, 1983), and Park City (Gill and Lund, 1984) with studies of specific hazards completed in the Tooele area (seismic hazards; Everitt and Kaliser, 1980) and Cedar City (collapsible soil hazard; Kaliser, 1977). The UGMS includes discussions of geologic hazards in its quadrangle maps and is now including geologic hazards maps and text in its county map series starting with the upcoming Kane County report. County-wide studies specifically addressing hazards have been performed in Davis (Kaliser and others, 1976) and Morgan (Kaliser, 1972) Counties, and hazards studies have been performed or used in delineating areas for hazards ordinances in Ogden, North Ogden, Logan, and Mapleton, as well as in Provo and Salt Lake City.

In much of the remainder of the state, however, hazards information is either unavailable or is difficult to obtain and not in a form easily used by local governments. Basic geologic mapping and data are commonly available but must be interpreted and translated to derive usable hazards maps. Geologic expertise is required to make these interpretations, and several projects are underway to identify and translate available information to derive generalized maps for use by local governments in identifying hazard areas. At present, compilation of hazards maps for the entire state at a scale of 1:750,000 and for the Wasatch Front portions of Weber, Davis, Salt Lake, Utah, and Juab Counties at scales of 1:24,000 and 1:100,000 is underway and scheduled for completion in 1988. In addition to maps, hazards libraries (Wasatch Front counties) and a bibliographic listing of hazards information (statewide), both with index maps showing study areas, are being compiled by Wasatch Front county geologists and the UGMS, respectively.

The suitable use of a hazards map is dependent in large part on its scale. Maps at scales of 1:250,000 to 1:1,000,000 or smaller are generally designed for use in statewide planning and are not suitable for use in city or county hazards ordinances except as a preliminary indicator of hazard areas. Maps at scales from 1:100,000 to 1:250,000 are most suitable for use in county planning in rural areas, but lack sufficient detail for city planning or planning in urbanized counties and generally are of limited value for use in hazards ordinances. Hazard maps at scales between 1:100,000 and those of standard site investigations (1:1,200 or larger) are best suited for use in ordinances to identify hazard areas. However, none of these generalized hazards maps replace the need for site-specific investigations.

SURVEY OF LOCAL GOVERNMENT ORDINANCES

UTAH

Those local governments in Utah which address geologic hazards do so in zoning, subdivision, and hillside ordinances as well as site development codes and regulations. Coverage in zoning ordinances consists of designating critical environmental zones, sensitive area zones, and hillside protection zones where development is prohibited or where specific studies are required prior to development. Hazards are also typically considered for subdividing land in development codes and subdivision or hillside ordinances. In some ordinances, hazards are considered only when applying for a conditional use permit or zoning change, or for specific types of projects such as planned unit developments and recreational (mountain, desert, seasonal occupation) developments. Some cities and counties do not address hazards at all, but in those that do, the overall approach consists of requiring geologic hazards studies in known hazard areas to be submitted for review during conceptual and preliminary planning phases of the permitting process. The principal differences in the ordinances are in the method by which hazard areas are determined and the qualifications required of performers and reviewers of these studies.

The results of the survey of city and county ordinances are included in appendices 1 and 2. The tables show which cities and counties have enacted ordinances addressing geologic hazards and whether hazard zone maps are included in ordinances. Those ordinances requiring geotechnical reports addressing hazards are indicated, as is the manner in which report preparers are defined and whether or not a geologic review is required. Finally, slope angles above which development is prohibited or restricted are listed.

Wasatch Front cities generally have the most strict and comprehensive land-use controls regarding hazards. Many cities outside the Wasatch Front have essentially no coverage of hazards other than flooding in their ordinances. Coverage by counties is more uniform with most counties having a means by which hazards are addressed. With the exception of Salt Lake County, however, Wasatch Front county ordinances are not any stricter than those of other counties. One reason for this is that little development occurs in the unincorporated parts of these counties because the county does not provide utilities such as sewer and water. Development generally requires annexation by a city, and the county does not believe it has a need for ordinances as comprehensive as those of the cities. The hazards generally addressed in ordinances are landsliding, surface fault rupture, liquefaction, flooding, and erosion. Debris-flow, rock-fall, subsidence, and shallow ground-water hazards are considered in a few of the ordinances.

Landslide hazards are considered in ordinances to some extent by restricting development on steep slopes. The maximum allowable slope varies among jurisdictions, but 30 percent is the most commonly used slope above which development is prohibited or restricted (appendices 1 and 2). Some jurisdictions have enacted hillside ordinances which require geologic reports for development in areas above a certain minimum slope angle. Allowance is generally made for waiver of this requirement by the planning commission if it determines that reports are not necessary. Development on active landslides and in rock-fall zones is prohibited in some ordinances.

Consideration of seismic hazards is somewhat less uniform. Of the four major seismic hazards (surface fault rupture, liquefaction, seismically induced slope failure, ground shaking), only surface fault rupture and liquefaction are generally covered in ordinances. In those ordinances which address active faults (Salt Lake City, Provo, cities in Davis County, Mapleton), development over fault traces is generally prohibited. Setbacks from faults are determined based on recommendations from technical reports prepared for the development. Ogden City and North Ogden set a minimum setback from active faults, prohibiting structures for human occupancy within 50 feet. Provo uses a similar 50-foot zone to indicate a hazard area requiring study, but does not prohibit development in this zone. Ordinances addressing liquefaction require that susceptible zones be identified and mitigation measures be recommended in geotechnical reports, but development is not prohibited. Only Mapleton has considered seismic slope stability in its ordinance, and does so by incorporating potentially unstable slopes in its hazard zone maps. Ground shaking is generally addressed in building codes rather than in hazards ordinances. Those jurisdictions which have adopted and enforced the Uniform Building Code require earthquake-resistant design and construction as specified in the Code for the appropriate seismic zone.

Flooding regulations generally involve prohibiting or controlling construction on the 100-year flood plain shown on FEMA Flood Insurance Rate Maps as mandated by participation in that federal program. Erosion is related to steepness of cut and fill slopes, and regulations are principally concerned with controlling erosion during and after development through revegetation and runoff control.

The majority of cities and counties with ordinances place the responsibility for identifying hazard areas on planning commissions, city councils, and building officials. Several cities have contracted with geologists to identify hazard areas. Other cities and counties require developers to perform studies either in all areas or just in areas defined in ordinances based on criteria such as slope.

Those who may prepare geologic hazards reports are generally not defined or are loosely defined as, "competent professionals," "person or firm qualified by training and experience to have a expert knowledge of the subject," or "licensed or having demonstrable expertise in the field of practice" (appendices 1 and 2). In some cases, specialties ranging from soils engineer and civil engineer to geotechnical engineer and engineering geologist are listed. For the most part, planning commissions and staffs, city engineers, and city councils are designated to review these reports, although in some cases the UGMS or a person or group designated by the planning commission is utilized. In general, no specific qualifications are listed for either preparers or reviewers of reports.

CALIFORNIA

While most states leave planning and zoning responsibilities to local governments, the State of California has enacted a statewide hazards reduction act to control development along potentially active faults. The Alquist-Priolo Special Studies Zones Act of 1972 provides for: 1) restriction of development over or near surface traces of active faults; 2) submission of geologic reports; 3) approval of projects by cities and counties; and, 4) disclosure of hazards by property sellers (Kockelman, 1985). The California State Geologist delineates Special Studies Zones that include "potentially and recently active" fault traces. Originally these zones were about ¼ mile wide, but currently they are 400-600 feet wide and are based on the best available information. Where faults consist of branching segments or other complexities, zones may be more than ¼ mile wide. Development is prohibited in these zones until a geologic report is prepared and reviewed by engineering geologists certified by the state. The state originally prohibited placement of structures for human occupancy across the trace of an active fault and considered the area within 50 feet of the fault to be underlain by active traces unless proven otherwise by a geologist. In later legislation, "single family wood-frame dwellings not exceeding two stories when not a part of a development of four or more dwellings" were excluded from the act. Cities and counties are allowed to have more stringent regulations than those required by the state, and some prohibit all structures within 50 feet of active fault traces.

In San Bernardino County, hazards are considered in a Safety Overlay District. The Safety Geologic (S-G) Overlay is designated in areas "on or adjacent to active earthquake fault traces" (based on Alquist-Priolo Special Studies Zones), "where landslides are prevalent," and "where liquefaction of the soil is associated with earthquake activity." Near faults, "development of all structures used for human occupancy, other than single-story wood-frame structures, shall take place fifty (50) feet or further from active earthquake fault traces." Critical facilities must be 150 feet or more from these faults. In landslide zones, "Measures shall be taken to offset the possible effects of landslides. A detailed geologic report identifying these measures shall be required prior to issuance of building permits," and all facilities in liquefaction and landslide hazard areas shall be constructed "to minimize or eliminate subsidence damage."

Santa Clara County has enacted a Geologic Ordinance for establishing minimum requirements for the geologic evaluation of land based on proposed land use and adopted official county hazard maps. The expressed purpose of the ordinance is to discourage development within a known geologic hazard area. The county hazard maps are color-coded to show areas where a geologic report is: 1) normally required (i.e., hazard area); 2) may be required; and 3) not normally required (i.e., non-hazard area). These areas are based on Alquist-Priolo Special Studies Zones Maps and relative seismic stability maps. High-risk areas for landsliding, compressible soils, and salt-water flooding are also included. The county employs a geologist to review reports required under the ordinance, and the county geologist's review provides the basis for approval or disapproval of the application. The ordinance also describes various levels of geologic reports required depending on the severity of the hazard, as defined on county hazard maps, and lists geologic report requirements.

Not all populated counties in California have ordinances as strict as those of San Bernardino and Santa Clara Counties. Sonoma County requires reports by registered geologists in hazard areas but has not adopted official hazard maps and does not provide for review by a registered geologist. Reports are required in areas of slopes of five horizontal to one vertical (20 percent) or steeper and in areas "likely to be affected by hazardous or potentially hazardous geologic conditions," and are reviewed by the chief building official. For further information, six examples of various seismic zonation techniques used by California cities and counties to mitigate earthquake hazards are included in Kockelman and Brabb (1979).

COLORADO

In 1974, the Colorado Geological Survey prepared model geologic hazard area control regulations for cities and counties. The model regulations recommended adoption of Chapter 70 of the Uniform Building Code and advocated protection of permitted land uses in geologic hazard areas by providing for geologic hazards investigations and avoidance or mitigation of hazard impacts at the time of initial construction. The model regulations recommended adoption of official Designated Geologic Hazard Area Maps with a requirement for a geologic report, prepared by a professional geologist with adequate experience in engineering geology, to accompany all applications for development permits in hazard areas. Under the proposed regulations, these permit applications were forwarded by the city or county to the Colorado Geological Survey for review, and these review comments were to be considered in evaluating the application.

Jefferson County, Colorado, has passed effective land-development regulations which address geologic hazards (McCalpin, 1985a, 1985b). Hazards maps at a scale of 1:24,000 by the U.S. Geological Survey are used in defining a Geologic Hazards Overlay zone. This zone overlays the existing zoning map, and within this zone reports must be prepared to address geologic hazards. The regulations include detailed guidelines for report contents and maps and require plans showing alternatives and solutions to abate and/or minimize the hazards. The report and plans (except for engineered structures) must be prepared by a qualified professional geologist and reviewed by the county geologist. Approval from the county geologist is required prior to plat approval. In the regulations, geologic hazards are defined and qualifications of geologists given.

DISCUSSION

Experience with both hazards and development pressures in California and Colorado have forced local governments to enact and enforce ordinances to control land. Utah can benefit from this experience and avoid some of the problems that have arisen in these states by following their example and strengthening existing ordinances. One of the most important lessons to be learned from past experience in California and Colorado as well as in Utah is that qualified engineering geologists must prepare and review reports. In California, the state registers geologists and certifies engineering geologists. In larger cities and urbanized counties, certified engineering geologists are maintained on the permanent, full-time government staff to review reports and perform other functions. Colorado defines a professional geologist by state statute, but has no registration of geologists and does not separately define an engineering geologist. However, geologic hazard area control regulations proposed by their state geological survey make it clear that qualified engineering geologists must prepare and review reports. Also, Jefferson County, which includes the Denver area, maintains an engineering geologist on its staff. Although many local government ordinances in Utah allow for required engineering geologic reports, the qualifications of those chosen by developers to do the work are generally not given. As a result, many reports submitted in conformance with these ordinances are done either by engineers or by geologists with little or no experience in engineering geology or geologic hazards assessment. However, even reports done by qualified engineering geologists are sometimes inadequate because of time and funding constraints placed on the consultant by the developer. This is a major problem in Utah, and experience in California has also shown that consultants' reports have been generally inadequate when first submitted (Stewart and others, 1977; Hart and Williams, 1978). Review by government geologists with feedback and discussion with consultants is a necessary and productive part of the process. Once the consultant receives the reviewer's comments, the nature and scope of any additional geologic work required can be discussed and agreed upon. If additional work is to involve engineers, hydrologists, or others, representatives with the necessary expertise should also be included in these discussions.

One major difference exists between the geology of Utah and that of California which has specific relevance to hazards ordinances. In California, the faults for which the Alquist-Priolo Special Studies Zones Act was written are strike-slip faults such as the San Andreas Fault, along which movement is horizontal with one side slipping laterally past the other (figure 3). Along such a fault, the zone of deformation accompanying surface rupture is symmetrical or similar on both sides of the fault. Hence, a symmetrical study zone of 50 feet either side of the fault was used to consider surface fault rupture. In Utah, movement on faults is chiefly vertical on so-called normal (dip-slip) faults. It has been well documented that the zone of deformation accompanying surface faulting on normal faults is much wider than along strike-slip faults, and that the widest zone occurs on the downdropped side (figure 3). In the 1983 Borah Peak, Idaho earthquake, the zone was as much as 300 feet wide.(Crone and Machette, 1984). The width of the zone is highly variable, and it is not appropriate to apply the 50-foot study area zone used in California to Utah. A much wider zone must generally be considered along Utah's faults.

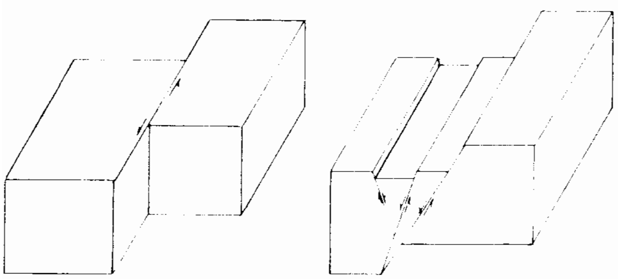

Figure 3. Diagrams illustrating differences between strike-slip and dip-slip (normal) faults indicating the wider, asymmetrical zone of deformation commonly associated with dip-slip faults such as the Wasatch fault.

CONCLUSIONS AND RECOMMENDATIONS

Ideally, geologic hazards should be considered in the master plan and zoning ordinance so that land use can accommodate hazards (Jaffe and others, 1981). If not presently included, such planning and zoning documents can be amended to address hazards by defining new zones or using overlay zones. Coverage of hazards in site development codes and subdivision ordinances can be effective but is less desirable because areas where hazards must be considered are not identified, and not all development is covered by subdivision ordinances. At whatever point in the process, the principal goal of a geologic hazards ordinance must be to provide a means for local government to require site-specific geologic hazards investigations where necessary in order to demonstrate that the land is suited for the proposed use or to recommend measures necessary to make the land suitable. In Utah, the responsibility for providing these investigations lies with the landowner or person requesting a permit from the local planning commission. The preliminary determination of where such investigations should be required must be made by local government. This can be done in several ways:

1. Produce maps at non-site-specific scales (generally 1:24,000 or smaller) depicting hazard areas where investigations and reports are required. This provides consistency and brings potential problems to the attention of developers early in the planning process. Any ordinance adopting such maps must also provide a means of revising maps based on new information.
2. Have a qualified engineering geologist on staff or under contract to review all plans and determine the areas where reports are needed on a project-by-project basis. This provides considerable flexibility, but does not ensure consistency or forewarn developers of potential problems prior to initial contact with the planning department.
3. Require a complete hazards evaluation at all sites regardless of location or known conditions. This is the most comprehensive and conservative approach, and it may result in unnecessary expense to property owners and developers by requiring reports when they may not be needed.

Once such reports are required, they must be reviewed when submitted and both the report and review comments presented to local government authorities for a decision. An outline of steps to be taken in ordinances both with and without geologic hazard maps is shown in table 1. Good examples of various approaches in ordinances for areas with geologic hazards maps include: 1) the model geologic hazard area control regulations developed by the Colorado Geological Survey, 2) the Provo City ordinance, 3) a geologic hazards overlay zone ordinance presently being developed in Salt Lake County, and 4) various California ordinances for metropolitan areas (e.g., Portola Valley, Santa Clara County).

Reports can be required for a broad range of purposes, but it should be apparent from each report that all major hazards have been considered. In some cases, this consideration is implicit in the use of hazards maps where it can be assumed that a hazard does not exist if not shown on the maps. However, unless these maps are at a sufficiently large scale, each hazard should still be addressed in the site evaluation. In order to facilitate the preparation and review of geologic reports, guidelines for report contents are helpful. Developers and their consultants may not be familiar with the type and extent of information necessary to satisfy ordinance requirements, and guidelines for hazard evaluations can either be listed in the ordinance or elsewhere, or discussed in a meeting with local government officials and their geologists. Listing of minimum

Table 1. Suggested topic outline for geologic hazards ordinances in areas with geologic hazards maps (A), and without geologic hazards maps (B).

A

1) Define boundaries of geologic hazards areas by establishing Geologic Hazards Zones (or equivalent) or officially adopting maps referenced to an ordinance.
2) Require geotechnical reports by qualified engineering geologists and engineers addressing hazards and, if necessary, recommending mitigation measures prior to development in geologic hazard areas.
3) Require review of geotechnical reports by county geologists or other qualified engineering geologists acting on behalf of local government.
4) Submit report and review comments to planning commission for action.
5) Amend geologic hazard area boundaries (zones or adopted maps) if proven necessary by site report.

B

1) Provide for review of all development proposals by county geologists or other qualified engineering geologists acting on behalf of local government to determine need for geotechnical reports.
2) Require geotechnical reports by qualified engineering geologists and engineers to address potential hazards indicated in review and, if necessary, to recommend mitigation measures. If initial reviews of development proposals are not performed, complete reports may be required for all sites.
3) Require review of geotechnical reports by county geologists or other qualified engineering geologists acting on behalf of local government.
4) Submit report and review comments to planning commission for action.

requirements for reports in the ordinances is difficult because the type and extent of study varies with the severity of the hazard and the proposed land use (subdivision vs. critical facility). The ordinance for the city of Provo is an example of one which sets minimum requirements for reports based on the type and severity of the hazard as depicted on hazard maps prepared for the city. However, an ordinance with such specific requirements can only be enacted if such specialized hazards maps are available. In Utah, these maps are not available in most areas and a more generalized approach is required. This may include allowing for contact with developers and their consultants prior to preparation of preliminary plans to define a scope of work for the study.

As an aid in defining the types of work required, the UGMS has published guidelines for the preparation and review of engineering geologic reports (UGMS Miscellaneous Publication M) and guidelines for evaluating surface fault rupture hazard (UGMS Miscellaneous Publication N), prepared by the Utah Section of the Association of Engineering Geologists. The guidelines for preparation and review of engineering geologic reports include much information in addition to that required for geologic hazards assessments, and the geologic hazards information requested in Sections III and IV of the guidelines will vary substantially depending on the extent of the hazards. Appendix 3 lists suggested types of studies to assess each major geologic hazard based on the UGMS's experience in reviewing reports and performing site investigations.

If studies identify the existence of a hazard at the site which presents an unacceptable risk to development, a mitigation plan must be included if development is recommended. The plans should be in sufficient detail and with sufficient supporting data to allow local government geologists to evaluate their effectiveness and adequacy. If the plan involves recommendations for or includes results of engineering and hydrologic investigations, these should be referred to qualified professionals for review and comment. If plans are deemed adequate, development may proceed as long as the report recommendations are carried out. If they are deemed inadequate, further work can be required or development can be denied.

Only geologists specializing in engineering geology should prepare and review geologic hazard reports (Stewart and others, 1977; Hart and Williams, 1978). Because Utah does not register geologists, minimum qualifications for geologists preparing and reviewing reports should be included in the ordinance. For ordinance purposes, the following definition of a qualified engineering geologist is recommended:

> A geologist who through education, training, and experience is able to assure that geologic factors affecting engineering works are recognized, adequately interpreted, and presented for use in engineering practice and for the protection of the public. The person should have at least a four-year (bachelor's) degree in geology, engineering

geology, or related field from an accredited university and at least three full years of experience in a responsible position* in the field of engineering geology.

> *A responsible position is one in which a person having individual control and direction of a geological project exercises the individual initiative, skill, and judgement in the investigation and interpretation of geologic features, or supervises such projects.

To administer an ordinance as suggested in this report, local governments must have access to a qualified geologist to perform reviews and to represent their interest in contacts with developers and their consultants. The Wasatch Front county geologists are presently providing these services for Weber, Davis, Salt Lake, Utah, and Juab Counties and associated cities. The UGMS provides such services for all local governments in the state as time and workload allow. For cities and counties without a need for a full-time geologist, it may be appropriate to retain a qualified engineering geologist under contract to represent their interests, as is commonly done with the city/county engineer position. The ordinance can provide that the cost of retaining such expertise be borne by the developer or applicant. Once a report is reviewed and approved and development begins, responsibility falls to planners, engineers, zoning administrators, and building inspectors to assure that the hazard mitigation recommendations included in the report are carried out.

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GLOSSARY

Active Fault—A fault that exhibits surface displacement during Holocene time (about the last 10,000 years)

Bedrock—The solid, undisturbed rock in place either at the ground surface or beneath surficial deposits of soil

Collapsible Soil—Low-density soil which collapses, when wetted for the first time since deposition, in a process termed hydrocompaction, resulting in ground subsidence and cracking

Earthquake—Perceptible trembling to violent shaking of the ground, produced by sudden displacement of rocks below and/or at the earth's surface

Engineering Geology—The application of geologic data, principles, and interpretation to naturally occurring earth materials so that geological factors affecting planning, design, construction, and maintenance of civil engineering works are properly recognized and utilized

Expansive Soil—Clay-rich soil which undergoes a change in volume with a change in moisture content; soil with a high shrink-swell potential which swells (expands) as moisture content increases and shrinks (contracts) as it decreases

Fault—A plane of breakage in rock or soil, along which displacement of the two sides of the plane has taken place due to tectonic forces

Fault Trace—The line of intersection of a fault with the earth's surface

Geologic Hazard—A naturally occurring or man-made geologic condition or phenomenon that may present a potential danger to life and property

Ground Motion—Shaking motions of the soil or rock during an earthquake

Ground Response—The reaction of the ground to bedrock shaking

Liquefaction—Temporary transformation of a cohesionless soil into a fluid mass accompanying earthquake ground shaking

Magnitude (earthquake)—Magnitude is related to that energy which is radiated from the earthquake source in the form of elastic waves. It is expressed in ordinary numbers and decimals. Magnitude was originally defined by C.F. Richter as a logarithm (base 10) of the maximum amplitude of a seismogram from a specific instrument at a distance of 100 km (62 miles) from the focus. For other distances or for instruments of other types, conversion to the standard is accomplished.

Potentially Active Fault—A fault that exhibits surface displacement during Quaternary time (about the last 2 million years)

Recurrence Interval—The average length of time between earthquake events of a specified magnitude. It is a statistical quantity and does not imply that the events will occur in that time interval.

Seiche—A wave on the surface of water in a lake commonly initiated by an earthquake

Seismicity—Earthquake activity

Slope Failure—Downslope movement of soil and rock under the influence of gravity, commonly termed landsliding (including planar and rotational slides, flows, falls, spreads, and raveling)

Subsidence—The downward settling or sinking of the ground

Surface Rupture—During an earthquake, the permanent displacement (or offset) of the earth's surface along a fault plane. Ground breakage at the earth's surface.

Tectonic—Pertaining to rock structure resulting from deformation of the earth's crust

Zone of Deformation—The zone along a fault trace in which natural soil and rock materials are disturbed (displaced, tilted, cracked) as a result of movement along the fault

Appendix 1
Survey of County Geologic Hazards Ordinances in Utah

	Ordinances/codes addressing geologic hazards		Geologic reports prior to development in hazards areas			Avg. % slope above which development is:	
County	Enacted (1)	Hazard areas mapped(2)	Required	Report preparer defined	Geologic review provided	Restricted	Prohibited
Beaver	---	---	---	---	---	---	---
Box Elder	X	---	X	---	UGMS	15	25
Cache	X	X	X	---	--- (4)	10	---
Carbon	---	---	---	---	---	---	30
Daggett	X	---	X	Competent professional experts.	---	---	---
Davis	---	---	---	---	---	---	---
Duchesne	X	---	X (3)	---	---	---	---
Emery	---	---	---	---	---	---	30
Garfield	X	---	X (3)	---	UGMS	---	30
Grand	X	---	---	---	---	---	---
Iron	X	X	X	Persons or firms licensed to practice their specialty or expertise in the State of Utah if such field of expertise is a licensed and/or regulated trade in this state.	---	30	---
Juab	X	---	---	---	---	---	30
Kane	X	---	X (3)	---	UGMS	---	30
Millard	---	---	---	---	---	---	---
Morgan	X	X	X (3)	Registered soils engineer, engineering geologist, or other qualified person (Soils Report); qualified professional team (Geologic Hazard Control Plans and Specifications).	--- (4)	25	---
Piute	X	---	X	---	---	---	30
Rich	X	---	X	Competent professionals.	---	30	---
Salt Lake	X	X	X	Person or firm qualified by training and experience to have an expert knowledge of subject.	---	20	30
San Juan	X	---	X	Geologist or soil engineer.	---	---	---
Sanpete	X	---	X	Engineer, geologist, or other person qualified by training and experience as determined by the planning commission (Impact Analysis); competent professionals (Geological Analysis).	---	30	---
Sevier	X	---	X (3)	---	---	---	---
Summit	X	---	X (3)	Engineer, geologist, or other person qualified by training and experience as determined by the planning commission.	---	30	---
Summit (Snyderville Basin Dist.)	X	---	X	---	---	---	40
Tooele	X	---	X (3)	---	UGMS	---	30
Uintah	---	---	---	---	---	---	---
Utah	X	---	X	---	---	---	---
Wasatch	X	---	X	---	--- (4)	---	30
Washington	X	---	X	Licensed civil engineer.	---	---	---
Wayne	---	---	---	---	---	---	---
Weber	X	---	X	---	---	25	---

(1) Counties considered not to have enacted geologic hazards ordinances/codes may have provisions in existing ordinances under which geologic hazards fall (i.e., exceptional topographic conditions), but they do not specifically address geologic hazards other than flooding. Counties with ordinances which address hazards but make no report requirement (Grand, Juab) prohibit development in hazard areas.

(2) Hazard areas defined by overlay zones or hillside protection zones.

(3) Reports addressing hazards are required in all areas, not just in hazard overlay zones or at request of government officials.

(4) Ordinance allows for review by UGMS or by a designated representative upon request from the Planning Commission, County Engineer, or other official.

Appendix 2
Survey of Selected City Geologic Hazards Ordinances in Utah

City	Ordinances/codes addressing geologic hazards: Enacted (1)	Hazard areas mapped(2)	Geologic reports prior to development in hazards areas: Required	Report preparer defined	Geologic review provided	Avg. % slope above which development is: Restricted	Prohibited
Beaver	---	---	---	---	---	---	---
Blanding	---	---	---	---	---	---	---
Bountiful	X	X	X	Persons or firms either licensed to practice their specialty or expertise in the State of Utah if such license for practice is required or by one having demonstrable expertise in such a field of practice.	---	---	30
Brigham City	--- (3)	---	---	---	---	---	---
Cedar City	X	---	X	---	---	---	---
Centerville	X	X	X	(Same as Bountiful)	---	---	30
Delta	---	---	---	---	---	---	---
Draper	---	---	---	---	---	---	---
Ephraim	---	---	---	---	---	---	---
Farmington	X	X	X	Person or firms licensed to practice their specialty in the State of Utah, if the required expertise is in their field of practice.	---	---	---
Green River	---	---	---	---	---	---	---
Heber City	X	---	X	Engineer, geologist, or other qualified by training and experience.	---	---	---
Kanab	---	---	---	---	---	---	---
Layton	X	X	X	(Same as Bountiful)	--- (6)	---	30
Logan	X	X	X	---	---	25	46
Manila	X	---	X	Competent professional experts.	---	---	---
Mapleton	X	X (4)	X	Professional geologist experienced and knowledgeable in the practice of engineering geology (Resolution).	--- (6)	---	---
Midvale	---	---	---	---	---	---	---
Moab	---	---	---	---	---	---	---
Morgan	---	---	---	---	---	---	---
Murray	X	---	X	Geologist or soils engineer.	---	---	---
North Ogden	X	X (4)	X	Engineering geologist recognized by UGMS.	--- (6)	15	---
No Salt Lake	X	X	X	(Same as Bountiful)	---	---	35
Ogden	X	X (4)	X	(Same as Bountiful)	---	---	30
Orem	X	--- (5)	X	Engineering geologist, civil engineer, geologist, soil scientist team or other qualified and competent team.	---	10	35
Panguitch	---	---	---	---	---	---	---
Park City	X (3)	---	X	---	---	---	---
Price	X	---	X	---	---	25	---
Provo	X	X (4)	X	Registered professional geotechnical engineer or engineering geologist (graduate in geology or engineering geology from an accredited university with at least 5 years professional experience and at least 3 years in field of engineering geology).	---	25	---
Richfield	---	---	---	---	---	---	---
Riverton	---	---	---	---	---	---	---
Roosevelt	---	---	---	---	---	---	---

Appendix 2 (cont.)
Survey of Selected City Geologic Hazards Ordinances in Utah

City	Ordinances/codes addressing geologic hazards: Enacted (1)	Hazard areas mapped(2)	Geologic reports prior to development in hazards areas: Required	Report preparer defined	Geologic review provided	Avg. % slope above which development is: Restricted	Prohibited
St. George	--- (3)	---	---	---	---	---	---
Salina	---	---	---	---	---	---	---
Salt Lake	X	X (4)	X	Person or firm qualified by training or experience to have knowledge of the subject.	--- (6)	---	40
Sandy	X	X	X	(Same as Bountiful)	---	---	30
So Salt Lake	---	---	---	---	---	---	---
Spanish Fork	X	X	X	Civil Engineer	---	10	---
Springville	---	---	---	---	---	---	---
Tooele	X	---	X	Geologist or soils engineer.	---	---	---
Tremonton	---	---	---	---	---	---	---
Vernal	---	---	---	---	---	---	---
Washington Terrace	--- (3)	---	---	---	---	---	---
West Jordan	---	---	---	---	---	---	---

(1) Many cities shown not to have enacted hazards ordinances may have flood-plain regulations, but otherwise do not specifically address geologic hazards.

(2) Hazard areas defined by Hillside, Critical Environmental, or Sensitive Area Overlay Zones; some are based on detailed hazard mapping referenced in ordinance.

(3) Ordinance being drafted or revised.

(4) Hazard areas (zones) based on detailed geologic hazards mapping rather than just slope or other non-geologic criteria.

(5) Ordinance applied to sensitive areas, hillside areas, seismic hazard areas, and flood plains defined but not mapped.

(6) Allows for review by authorized representative of city engineer, planning commission, or city council.

Appendix 3

Suggested Studies to Address Geologic Hazards

Slope failure—Perform an initial geologic evaluation to identify any evidence of past slope failures, including debris flows. If evidence is present, assess the age of the movement, probable cause of movement, and present degree of stability, particularly if it relates to man's activities. If no evidence of past slope failures is found, a qualitative assessment of natural slope stability can be made based on material type, ground-water conditions, slope, and stability of other similar slopes. In some cases a slope stability analysis based on soil test data by a qualified engineer may be advisable.

Earthquake hazard—The ground-shaking hazard can be initially addressed through reference to the Uniform Building Code and Utah Seismic Safety Advisory Council seismic zonations. However, the requirements listed in these documents should be considered minimum requirements and recent studies by Hays and King (1982) and Rodgers and others (1984) indicate that they may be inadequate, particularly in central valley locations along the Wasatch Front. For certain construction (large buildings, critical facilities), investigations to evaluate site response to ground shaking should be performed by qualified geologists and engineers. If the site is in a zone of possible surface fault rupture, faults in the area should be delineated based on geologic mapping and, when necessary, subsurface investigations. Subsurface investigations should define whether faults are active (i.e., movement during the last 10,000 years) and, if so, the width of the zone of deformation. The extent of subsurface investigations will vary depending on the proposed land use, and in some cases an evaluation of the time of last faulting, time interval between events (recurrence), and amount of offset should be considered. Fault traces should be accurately mapped from surface evidence and trench data. Trenches should extend from the main fault(s) outward, particularly across the downdropped side, until the zone of deformation is delineated and undisturbed material encountered. Recommendations for setbacks from faults and zones of deformation can then be given based on these site-specific investigations. Liquefaction should be addressed through reference to liquefaction potential maps if available. Specific studies of seismic slope stability, liquefaction potential, and flooding (dam failure inundation, seiches) by qualified engineers and hydrologists may be appropriate in some cases.

Adverse soil foundation conditions—Standard soil foundation investigations should be performed by qualified engineers and geologists to identify expansive, collapsible, gypsiferous, compressible, or other problem soils. Such studies serve as the basis for foundation design and generally involve laboratory soil testing.

Flooding (stream, lake, ground water)—Perform an initial geologic evaluation to determine if the site is in a likely flood area. If so, consult FEMA Flood Insurance Rate Maps or other surface flooding maps. If sufficient information is not available, the geologist should recommend that detailed studies be performed by hydrologists, engineers, or other qualified professionals. Where lake and ground-water flooding is involved, studies to define present and previous levels should be conducted. Such studies may include a search of historic records, consultation with other professionals, subsurface investigations, and surficial mapping of shorelines.

Other hazards—Hazards such as subsidence, erosion, avalanches, and volcanic activity require specialized investigations. Studies are generally not necessary, but these hazards are locally significant and a geologist should recognize where studies are required and recommend those most qualified to perform them.